

Executive Summary

West Coast Regional Applied Ballast Management Research and Demonstration Project

**Produced for
The US Fish and Wildlife Service
The National Oceanic and Atmospheric Administration
The Port of Oakland
and
The State Water Resources Control Board**

**By
California State Lands Commission
Marine Facilities Division
Marine Invasive Species Program
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BACKGROUND

In 1999, the California State Legislature passed Assembly Bill 703. Under Section 71210 (a), the state is required to evaluate alternatives for managing ballast water for the purpose of eliminating the discharge of non indigenous species into the waters of the state or into waters that impact the waters of the state.

Because of the large volume and frequency of possible introductions, ballast water from commercial vessels is currently the most frequently cited vector for the worldwide transfer of non indigenous aquatic species (NAS). Ballast water may contain an enormous number of diverse organisms. A recent study conducted on oil tankers arriving in Prince William Sound, Alaska found an average of 12,637 total organisms per cubic meter in the 169 vessels that were surveyed (Hines et al., 2000). The risk of introduction of NAS has significantly increased in recent times because vessels are faster and carry a tremendous amount of ballast water relative to ships just a few decades ago. For example, in the Great Lakes there were 90 known introductions during the 150 years between 1810 and 1959. In only 30 years between 1960 and 1990, there were 43 known introductions (Mills et al., 1993). This pattern is mirrored in the San Francisco Bay Estuary, where research indicates that prior to 1960 one new species became established about every 55 weeks. Since 1960, this has increased to one every 14 weeks (Cohen and Carlton 1998).

Once introduced, invasive species are likely to become a permanent part of an ecosystem, and can cause economic and environmental impacts. The zebra mussel (*Dreissena polymorpha*) is probably the best-known non indigenous invasive species in the U.S. Since its accidental introduction to the Great Lakes via shipping in the 1980s, the zebra mussel has infested over 50% of U.S. freshwater waterways. Economic impacts primarily associated with physically clearing the mussels from power station and industrial cooling pipes total \$5 billion annually (Pimentel et al., 1999).

Another example, the Asian clam (*Corbicula fluminea*), was probably introduced via ballast water from Southeast Asia at the beginning of the 20th century, and is now found in 36 of the continental states. Although less studied than the zebra mussel, it may be the world's most invasive species. It is extremely efficient at filtering nutrients out of the water and therefore affects nutrient dynamics. Few studies have been done on the ecological impacts on native biota, and there is no agreement as to whether or not they negatively impact native species. However, there has been considerable economic impact due to fouling of raw water systems, particularly power stations. The annual cost for control and repair efforts resulting from the Asian clam at these stations has been estimated at approximately \$1 billion (Isom 1986).

Introduction of marine species via ballast water is also of concern to the aquaculture industry. Aquaculture is the practice of raising aquatic organisms, such as clams, oysters, mussels, trout, salmon, etc. rather than harvesting them in their natural state. The NAS, European green crab (*Carcinus maenas*) first identified on the East Coast in the early 1800's, now ranges up the entire West Coast of the United States. This species preys on native crabs, clams, and small oysters, causing considerable damage to commercial shellfish beds. The economic impact nationwide is estimated to be \$44 million annually (Lafferty and Kuris 1996).

Ballast water has been documented to contain a number of pathogens causing economic impacts and public health concerns. In 1991, a strain of *Vibrio cholera* was found in the ballast water of three ships near Mobile, Alabama. Sometime thereafter, the bacterium was found present in local oysters (McCarthy and Khambaty 1994). A recent study of ballast water from vessel visiting the Chesapeake Bay showed *V. cholera* in plankton samples collected from all

ships (Ruiz et al., 2000). Ballast water and sediments can also harbor toxic dinoflagellates, which cause paralytic shellfish poisoning (Hallegraeff 1998).

The best and most cost-effective method of addressing the problem of invasive species in ballast water is prevention. Several options have been proposed to prevent new introductions through ballast management such as retention of ballast water, open-ocean exchange, or the use of technologies to treat ballast water before it is discharged. However, there are associated problems for each of these proposed management practices.

Retaining ballast water onboard operational vessels is generally not feasible under normal ship operations such as loading and unloading cargo, and sometimes for safety reasons during navigation to maintain trim and stability. Although a small fraction of vessels are capable of retaining ballast water onboard, this technique is not an option for the majority of ocean going vessels.

The most common ballast water management technique applied to prevent new introductions is open-ocean ballast water exchange. During open-ocean exchange, water taken on in near shore environments is replaced with open-ocean water. Open-ocean ballast water exchange is currently the most utilized management method because most vessels can conduct an exchange without vessel retrofitting. Ballast water exchange is also relatively inexpensive and can be done while the vessel is underway (Dames and Moore 1999). However, under some conditions ballast water exchange can result in dangerous vessel instability, putting the safety of the vessel and crew at risk (NRC 1996).

The efficiency of ballast water exchange at removing entrained organisms is also a major concern. Original estimates of exchange efficiencies were as high as 99.9 percent. However, field tests have revealed efficiencies between 70 and 90 percent (Ruiz et al. 1998). Due to effectiveness and vessel safety concerns, open-ocean ballast water exchange is viewed as an interim solution, to be used until more effective treatment technologies are identified (Falkner 2000).

A variety of treatment technologies have been suggested for the removal or reduction of organisms found in ballast water. Numerous ballast water treatment technologies are under development. Though the use of alternative treatment technologies is allowed under the law in California, no alternative technologies have been adequately tested or approved. Laboratory tests alone cannot fully demonstrate the practical effectiveness of a treatment on an active commercial vessel; therefore, tests are needed on working vessels in real world situations.

In August 2000, the California State Lands Commission (CSLC) was awarded a \$150,000.00 grant from the US Fish and Wildlife Service (USFWS) to implement the West Coast Regional Applied Ballast Management Research and Demonstration Project (West Coast Demonstration Project (Appendix A – USFWS Proposal)). The West Coast Demonstration Project was an inter-agency pilot project to acquire and distribute information regarding applied alternatives for ballast water management. Initially, the West Coast Demonstration project was proposed as a feasibility study to assess the difference in cost between treatment technology installations onboard a vessel versus retrofitting a vessel for a shore-side treatment facility. After finding a similar feasibility study had already been completed, the West Coast Demonstration project was redesigned to assess efficacy of an onboard ballast water treatment system. In December 2000, the Port of Oakland agreed to match the USFWS funds, doubling the funds available for this project, making it possible to evaluate the efficacy of ballast water treatment systems onboard at least two vessels (Appendix B – Port of Oakland Proposal). US Fish and Wildlife

Service funds were awarded in September 2000 and utilized through September 2002. Port of Oakland funds were awarded in January 2001 and utilized through August 2004. Additionally, the State Water Resources Control Board (SWRCB) received \$150,000 from the Exotic Species Control Fund to evaluate alternatives for treating and managing ballast water. Total funding provided by the USFWS, SWRCB and the Port of Oakland for the West Coast Demonstration Project combined to a total of \$450,000.

In 2001, the California State Lands Commission (CSLC) teamed up with the State Water Resources Control Board (SWRCB), and initiated the West Coast Demonstration Project. The project timeline and distribution of funds were considerably modified over the span of the project due to changes in the scope of work and necessary system adaptations. Previously available engineering studies modified the scope of work to support the retrofitting of an onboard ballast water treatment system instead of a feasibility study for shore-side treatment. Once the project was underway, engineering complications with vessel retrofits extended the project timeline.

Project Objectives

The West Coast Demonstration Project objectives were to: 1) provide well researched cost estimates and proven ballast water treatment options to the maritime industry, and 2) conduct applied research, in cooperation with the Port of Oakland, the State Water Resources Control Board, the U.S. Coast Guard, the maritime industry, and ballast water equipment vendors, on practical, cost effective methods of ballast water treatment that might later be implemented on a state, regional, national or international scale.

Identification of Vessels

CSLC working with the Great Lakes Ballast Technology Demonstration Project (GLBTDP), Matson Navigation, Polar Tankers Inc., and Princess Cruises identified three vessels initially considered for participation in the West Coast Demonstration Project. Because of issues related to overall capital costs and intrinsic safety, Polar Tankers, Inc. declined to participate in the Project. The two remaining ships, the Sea Princess (Princess Cruises) and the R.J. Pfeiffer (Matson Navigation) elected to install the OptiMar System (Appendices C & D).

The Sea Princess is a UK flagged, 77499 GT passenger ship with 11 ballast water tanks (2,287 m³) and 2 ballast water pumps (220 m³/hr). The R.J. Pfeiffer is a US flagged, 2420 TEU containership. The vessel has 26 ballast water tanks (14,600 m³) and 2 ballast water pumps (350 m³/hr).

Project Specifications

Project specifications for shipboard evaluations of the Sea Princess and R. J. Pfeiffer were outlined in each contract agreement as follows:

- 1) Statements of work detailing criteria used for technology selection, all project deliverables including system drawings, engineering designs, estimated costs for installation, construction, and system operation, a statement of commitment as well as monitoring and evaluation results.
- 2) Documentation of operational and maintenance requirements for the OptiMar treatment system during operations at sea.
- 3) Quarterly progress reports and a final summary report (with specific content and timelines outlined in contract agreement). At a minimum, quarterly reports included information regarding costs of operating the treatment system versus conducting ballast water exchange, costs of crew training, operational impacts to the vessel, ballast water pumping rates, and time to ballast with the tested system versus rates and time when conducting an exchange. Lastly, the summary reports were to provide an estimate of the operational costs and impacts that would

be incurred over the life of the vessel. Budget and payment provisions as well as special terms and conditions were further detailed in the contract agreements.

OptiMar Ballast Water Treatment Systems

The OptiMar Ballast System (OptiMar system) manufactured by Hyde Marine/OptiMarin AS of Stavanger, Norway was installed and tested aboard the Sea Princess in the fall of 2001, and on the R.J. Pfeiffer in the fall of 2003. The OptiMar system treats ballast water with a two step process beginning with a cyclonic separation chamber (MicroKill Cyclonic Separator) to first dispose of larger particles and organisms before exposing the remaining 'clean' ballast water to ultraviolet irradiation (MicroKill UV unit) for treatment of smaller organisms. The system was designed to treat ballast water during flow through ballasting procedure versus empty refill ballast methods. This system was selected because it had undergone limited testing and evaluation with promising preliminary results, and was requested by both ship owners.

Sea Princess

Princess Cruises initially installed a first generation OptiMar system onboard the Regal Princess in March 2000; limited test results indicated the system's performance was at least equivalent to mid-ocean exchange. Onboard the Sea Princess, a second generation OptiMar system was installed with design improvements. The Sea Princess OptiMar system is comprised of two main components, the Model SKX 200 MicroKill Cyclonic Separator to remove particulate, and the LP 400-14-200 XF MicroKill UV unit.

Three evaluation cruises were completed onboard the Sea Princess as she traveled between Long Beach, California and Mexican ports in October/November 2001 and in October 2002. The first two Sea Princess cruises (SP1 & SP2) identified large uncontrollable tank variations that impaired quantitative evaluation of treatment efficacy. The measured efficacy of the OptiMar system was significantly enhanced after installation problems were addressed for the third Sea Princess cruise (SP3). Given several problems identified with system engineering and evaluation cruises for SP1 and SP2, the summary of efficacy testing and results focus on evaluation results for SP3.

RJ Pfeiffer

Full-scale engineering designs for the R.J. Pfeiffer were previously funded by the Great Lakes Ballast Technology Demonstration Project (Great Lakes Demonstration Project) and were made available for the West Coast Demonstration Project. Originally, the Great Lakes Demonstration project developed engineering studies to evaluate ship particulars and vessel routes to determine the most appropriate ballast water treatment system for installation, but had not allocated funding to install or analyze efficacy of the recommended treatment system. Subsequently, the West Coast Demonstration project provided funding for the installation and evaluation of the OptiMar system onboard the R.J. Pfeiffer (Falkner 2001).

The OptiMar system originally installed onboard the RJ Pfeiffer in the first quarter of 2002 consisted of a low pressure MicroKill Model HRN 350 8" Cyclonic Separator piped in series with a MicroKill Model LP 400-16-200 XFZ Ultra-Violet unit similar to that installed onboard the Sea Princess. Propulsion vibrations from the engine caused quartz tubes to break inside the UV chamber, which resulted in electrical malfunction. Due to these problems, the first evaluation trip was rescheduled from early summer to early July, then late July, and finally August as problems with vibrations continued. After multiple adjustments to the system, a representative from the manufacturer concluded that the 16-lamp, low pressure UV chamber that had been installed was not a suitable unit for this application.

A new medium pressure system was designed and manufactured by OptiMar in late 2002 under warranty as a replacement for the original low-pressure unit. The MicroKill Model UV-7, 3kW-250 unit has a single UV lamp, and is considered a more rugged design able to withstand the vibrations encountered on a ship such as the RJ Pfeiffer. The new design was installed in February 2003, and the research team performed evaluation tests during July 2003 (Matson Navigation Company, Inc. 2004).

Efficacy Testing

Analysis of the OptiMar system's effectiveness was performed in partnership between the CSLC and the SWRCB. A collaborative research team composed of scientists from the California State University System, Moss Landing Marine Laboratories (Principal Investigators: Rusty Fairey and Nick Welschmeyer) and the Romberg Tiburon Center for Environmental Studies (Principal Investigator: Stephen Bollens), were contracted by CSLC and SWRCB to evaluate the efficacy of each vessel's treatment system (Appendix E – Onboard Testing of Ballast Treatment Efficiency: Summary Report).

Each shipboard evaluation was focused to determine if the treatment removed or sterilized plankton entering and leaving the ship's ballast tanks. For both vessels, efficacy tests focused specifically on comparisons between 'control' and 'treatment' samples. All tests were conducted under routine vessel operating conditions.

General Experimental Design

All test cruises onboard the Sea Princess were in coastal waters with no opportunity to conduct open-ocean exchange. Therefore, experiment methods onboard the Sea Princess focused on comparisons between 'control' and 'treatment' samples. The RJ Pfeiffer had a transit route between Honolulu and Oakland, providing ideal circumstances to compare 'control' and 'treated' samples with a third treatment, open-ocean 'exchange' samples.

The OptiMar System was installed on both vessels with in-line sampling ports along the ballast piping system that allowed water to be sampled before and after UV/Hydrocyclone exposure during the ballasting phase, as well as during the de-ballasting phase. All sampling took place from within the engine room, eliminating the need for direct access to individual tanks through deck lids or sounding pipes.

No standardized test assays were available that could be applied to verify removal or sterilization of all biota. Working with the U.S. Coast Guard, a range of biochemical, physiological and microscopic techniques were applied to evaluate the most expected groups of organisms. Project methods included laboratory tests for viruses, bacteria, phytoplankton, ATP/Particulate Organic Carbon, and zooplankton. Test assays were used to measure two broad categories of plankton, one category for concentration levels such as chlorophyll a ($\mu\text{g/L}$), and zooplankton densities (individuals/volume), and a second category to reflect metabolic activity such as zooplankton and bacterial survivorship. As appropriate, nuclear fluorescence staining and Pulse Amplitude Modulated (PAM) Fluorescence analysis were performed to measure photosynthetic production in phytoplankton samples. Streak plating of cultivable bacteria was utilized to evaluate bacterial 'growth' potential where direct cell enumeration was otherwise difficult. For the analysis of larger metazoan zooplankton, fresh samples were visually inspected for live/dead counts. (Welschmeyer et al. 2004, Appendix E).

Sea Princess

Two Ballast tank time series experiments for treatment vs. control tanks were performed during the SP3 voyage to test the effect of the OptiMar system on plankton density and survivorship

over time. One tank was filled with treated seawater and the other tank was filled with untreated water as a control. Sampling took place at intervals of 0 hour, 24 hours, and 48 hours. Enclosure experiments (treatment vs. control) were applied in addition to 'ballast tank' experiments, using shipboard plastic enclosures. The enclosures provided samples without the introduced variability of 'tank effects', which could introduce sources of variability such as settling/resuspension within the tank and valve/plumbing contamination upon sampling (Welschmeyer et al. 2004).

R.J. Pfeiffer

To compare the effects of the OptiMar system and open-ocean exchange, six ballast tanks were sampled during the shipboard evaluation. Two duplicate tanks were filled with treated seawater, two were filled with untreated seawater, and the last two duplicate tanks were exchanged by the flow-through method with open-ocean seawater. All tanks were sampled at 1 hour, 48 hours, and 96 hours (with the exception of the open-ocean exchanged tanks which were sampled at 72 hours and 96 hours). Enclosure experiments similar to the methods applied on the SP3 evaluation were also practiced during the R.J. Pfeiffer evaluation voyages (Welschmeyer et al. 2004).

Efficacy Test Results

Most parameters of microbial and zooplankton samples decreased over time inside both control and treatment tanks for all three evaluation voyages. Throughout most time-series experiments, photochemical quantum yield, chlorophyll a, particulate organic carbon (POC) and ATP decreased in ballast tanks. Compared to the corresponding control samples, photochemical yield decreased in all UV treated samples. UV exposure produced near instantaneous effects on phytoplankton photochemical efficiency, and photochemical yield showed no signs of recovery during the experiments. The PAM fluorometric technique produced the most consistent results and the best precision of the analytical microbial techniques used in this study (Welschmeyer et al. 2004).

Concentrations of chlorophyll a and ATP were reduced in all UV treatments conducted in ballast tanks for all three evaluation voyages, though these results were not always reflected in enclosure experiments. After 96 hours of ballast tank containment, the ATP and chlorophyll a levels in UV treatment tanks approached levels found in the open-ocean exchange water. Bulk particulate organic carbon (POC) also showed decreases in ballast tanks for both controls and treated tanks; however, enclosure experiments show less reduction than tank samples (Welschmeyer et al. 2004).

Density of live zooplankton decreased over the first 24 hours in both control and treatment tanks for all three evaluation voyages. The decrease of live zooplankton was more dramatic in the treatment tanks, and onboard the R.J. Pfeiffer, densities in the open-ocean exchange treatment was similar to both the UV treated and control tanks (Welschmeyer et al. 2004).

Over-all, experiment results show that UV treatment resulted in a higher level of sterilization than measured in controls. However, it is important to note that prolonged (96 hours) tank containment resulted in reduced survivorship and biological concentrations in both controls and UV treatments. The collective measurements of plankton metabolism and survivorship showed that the compositions of ATP/POC bacterial colony growth, phytoplankton photochemical efficiency, and zooplankton survivorship were comparable in UV treatment tanks and open-ocean exchange tanks (Welschmeyer et al. 2004).

Engineering and Operational Findings

The West Coast Demonstration project identified several structural and operational issues to be considered in future installations of the OptiMar system. System modifications for both vessels were necessary to address corrosion, pipeline cross contamination, vibration frequencies and associated problems with quartz tubing inside of the UV chamber.

Onboard the Sea Princess, initial operations of the OptiMar system revealed corrosion issues due to incompatible metals and gray water cross contamination. These problems were eliminated by replacing carbon steel with galvanized steel and by separating ballast water pipelines from gray water pipelines. Minor issues with the UV chamber caused by engine vibrations were observed and resolved by strengthened anchoring of the UV tubes. In total, costs of system installation and modifications onboard the Sea Princess exceeded \$200,000. It is projected that continued system maintenance and operation will cost near \$40,000 annually (Wright 2004).

Prior to efficacy testing of the OptiMar system onboard the R.J. Pfeiffer, it was discovered that vibration frequencies during ship operations at sea were causing the quartz tubes around the UV lamps to break. This allowed salt water to leak out of the head of the UV unit, causing an electrical shortage. After several unsuccessful attempts to reduce the effects from vibration frequencies, the original 16-lamp UV-system was removed and replaced with a single-lamp system, designed to better withstand the vibrations encountered onboard the R.J. Pfeiffer. After several weeks of fine-tuning with the new UV system, all issues associated with engine vibrations and tube failures were resolved. Final costs of system installation exceeded original estimates by approximately \$80,000. Total labor and material costs for installation of the OptiMar system were approximately \$431,605. With limited use to date, it is difficult to estimate the annual costs of operation and maintenance. The new single bulb system design appears to perform with very little maintenance needed. It is projected that continued system maintenance and operation will cost near \$6,000 annually (Matson Navigation Company, Inc. 2004).

Project Conclusions

Installation and engineering problems addressed during the West Coast Demonstration project will offer insight for future treatment system designs and vessel retrofits. The West Coast Demonstration project provided evidence that treatment system installation and operational issues will likely be vessel specific. As discussed above, installation and design issues addressed onboard the Sea Princess were unique to issues addressed onboard the R.J. Pfeiffer. In general, future design considerations for the OptiMar system should ensure that existing gray water pipelines are separate from ballast water pipelines, treatment system and vessel pipeline metals are compatible, and lastly that the UV chamber is designed for vessel specific engine vibrations.

Once the OptiMar system was installed and functioning correctly, scientific testing suggests the system may be a feasible alternative to open ocean exchange in terms of treatment efficacy. Bacterial colony growth and plankton survivorship were found to be comparable in UV treatment tanks and open ocean exchange tanks. It is worth noting that in both control and treatment tanks, microbial and zooplankton samples decreased over time suggesting tank containment alone contributes to organism survivorship. Enclosure experiments support this observation by showing less reduction in Chlorophyll a and ATP measurements than tank control samples. Further studies are warranted in order to clarify and answer unresolved questions regarding experimental design, and tank effects versus treatment effects.

Conclusions produced during the span of this project not only offer valuable information, but also raise compelling questions for future studies. Many of these questions raised during the project are consistent with pre-existing unknowns from similar projects. How can 'tank effect' best be accounted for while developing sample designs? How can the internal variability found within tanks be addressed for future evaluation efforts? Were the in-line sampling ports installed along the ballast piping system most representative of ballast conditions before and after treatment?

Evaluation of ballast water management alternatives requires a broad range of technical considerations. The West Coast Demonstration project is one step forward in a highly comprehensive process. Future projects to evaluate ballast water management alternatives will now be able to incorporate lessons learned from the West Coast Demonstration project and as a result further advance the evaluation process.

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APPENDICES

Appendix A: USFWS Project Proposal

Appendix B: Port of Oakland Project Proposal

Appendix C: Princess Cruises Summary Report

Appendix D: Matson Navigation Summary Report

Appendix E: Onboard Testing of Ballast Treatment Efficiency: Summary Report